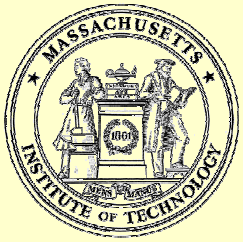


Injector Options for a 5-10 GeV Polarized Electron Ring for a High Luminosity Electron Ion Collider at Brookhaven National Lab

M. Farkhondeh, W. Franklin, W.S. Graves, R. Milner,
C. Tschalar, J.B. van der Laan, D. Wang,
F. Wang, A. Zolfaghari, T. Zwart

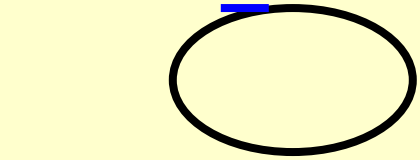
D. Barber, V. Pitsin, Y. Shatunov

M.I.T. Laboratory for Nuclear Science

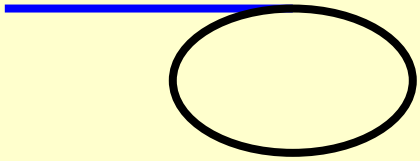
Operated by Massachusetts Institute of Technology for the U.S. Department of Energy

Injection Options

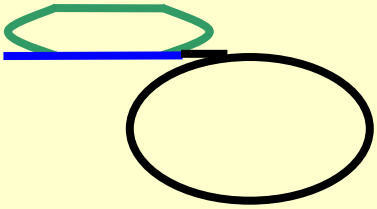
2 GeV Copper Linac
2-10 GeV Ramping Ring



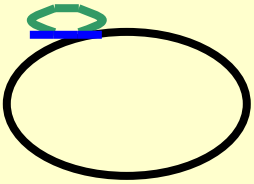
10 GeV Copper Linac
5-10 GeV Static Ring



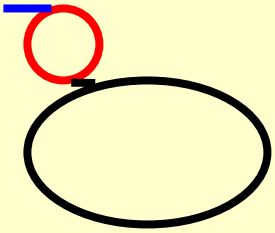
5 GeV Superconducting Linac
One Recirculation
5-10 GeV Static Ring



1 GeV Copper Linac
One Recirculation
2-10 GeV Ramping Ring



2 GeV Copper Linac
2-10 GeV Ramping Booster Ring
5-10 GeV Static Ring



The injector topology will largely be determined by strong "external'' forces

- Gross Constraints
  - Ring Polarization Properties (?)
  - Radiation Power (~10 kW/m)
  - Ring Size (~1 km)
  - Cost
- Outstanding Questions
  - Energy (10 GeV ?)
  - Polarized Positrons (?)
  - Detector Cycling (5 Minutes ?)
- Injector Choices
  - Copper/SC Linac ?
  - Recirculating Linac ?
  - Booster Ring ?
  - Polarized Source ?
  - Ramping Main Ring ?
  - Polarizing Main Ring ?

Radiation &Polarization Formulae

Derbenev Kondratenko Mane Formula

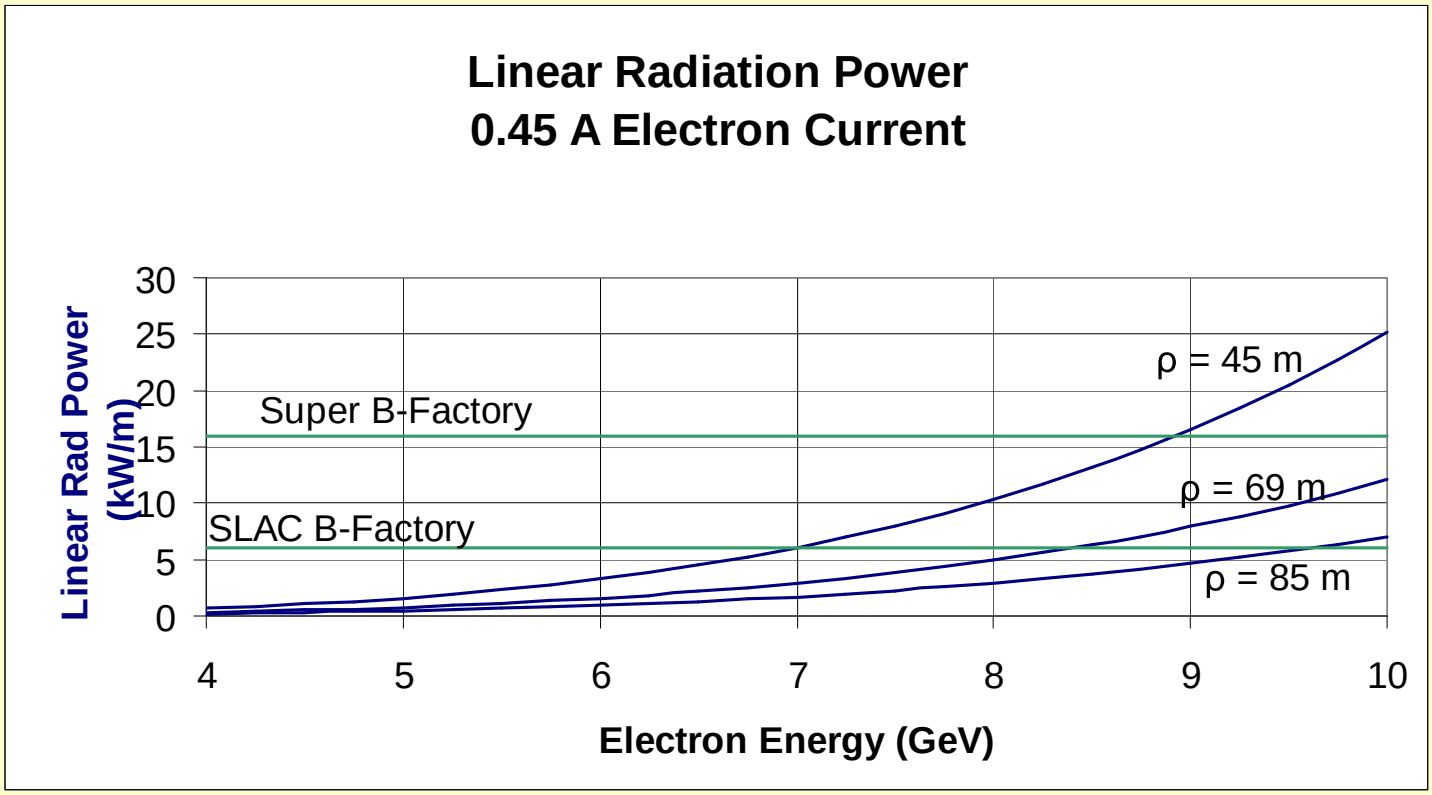
$$P_{eq} = \frac{\left\{\frac{1}{|\rho|^3}\hat{b}\cdot\left(\hat{n}-\gamma\frac{\partial\hat{n}}{\partial\gamma}\right)\right\}}{\left\{\frac{1}{|\rho|^3}\left(1-\frac{2}{9}(\hat{n}\cdot\hat{v})^2+\frac{11}{18}\left(\gamma\frac{\partial\hat{n}}{\partial\gamma}\right)^2\right)\right\}}$$

Time Constant

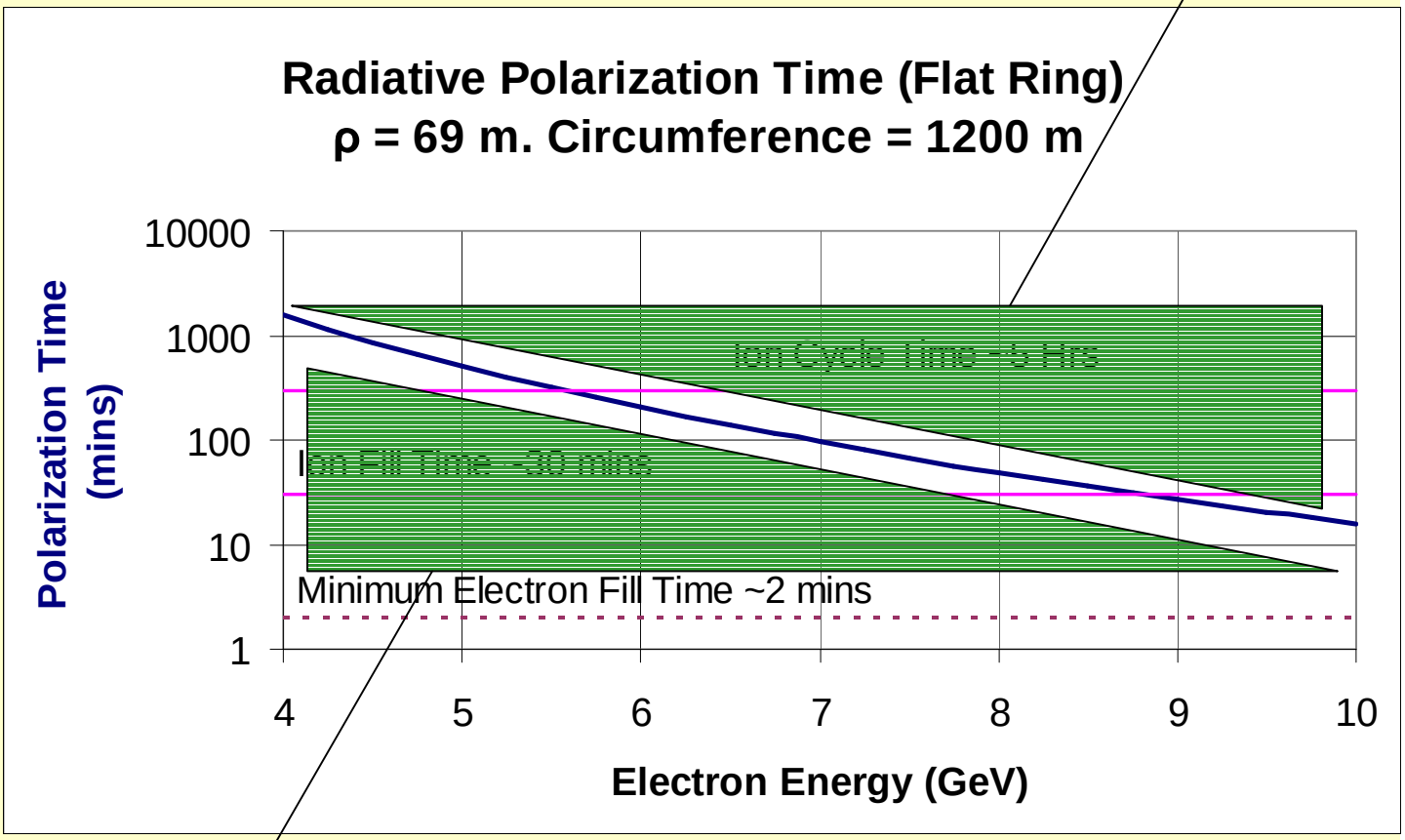
$$\tau^{-1} = \frac{5\sqrt{3}}{8}\frac{\hbar e^2}{m^2c^2}\left(1-\frac{2}{9}(\hat{n}\cdot\hat{v})^2+\frac{11}{18}\left(\gamma\frac{\partial\hat{n}}{\partial\gamma}\right)^2\right)$$

Synchrotron Radiation Power

$$P = C_\gamma \gamma^4$$


Linear Radiation Power
0.45 A Electron Current
Linear Rad Power (kW/m)
30
25
20
15
10
5
0
Super B-Factory
SLAC B-Factory
ρ = 45 m
ρ = 69 m
ρ = 85 m
4
5
6
7
8
9
10
Electron Energy (GeV)

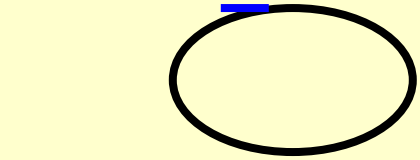
Bigger ρ
(Bigger Ring)



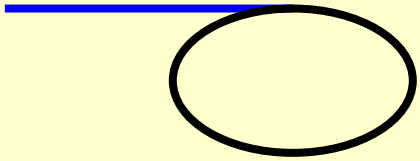
Wigglers

Injection Options

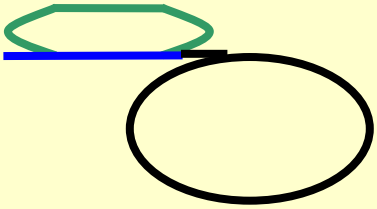
2 GeV Copper Linac
2-10 GeV Ramping Ring



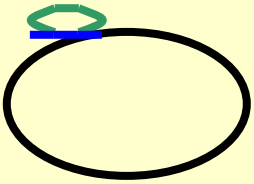
10 GeV Copper Linac
5-10 GeV Static Ring



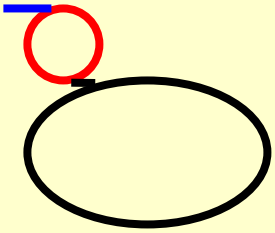
5 GeV Superconducting Linac
One Recirculation
5-10 GeV Static Ring



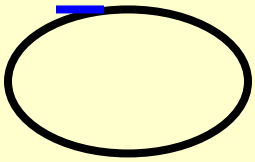
1 GeV Copper Linac
One Recirculation
2-10 GeV Ramping Ring



2 GeV Copper Linac
2-10 GeV Ramping Booster Ring
5-10 GeV Static Ring



2 GeV Copper Linac
2-10 GeV Ramping Ring



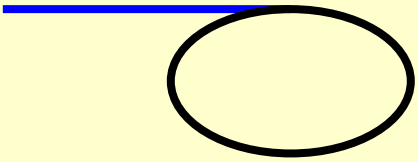
Electron Source	**Unpolarized** **1 us** **10 Hz** **< 1% Duty Factor**	
Linac	**2 GeV Copper** **2.856 GHz** **SLED RF compression, 20 MV/m** **100 m Active Length** **125 m Total Length** **< 2 μs** **10 Hz** **<0.1% Duty Factor**	~ 1 Minute Fill
Recirculation	**None**	
Ring	**Ramping Ring** **Radiation and Damping Wigglers** **$\tau_{Polarization}$ << Electron Storage Time**	~ 10 Minutes Ramp/Polarize >~ 1 Hr Store
Polarization	**Polarize in Ring** **Determined by Sokolov Ternov**	

Wigglers on/off ? Live time $\eta > 95\%$

No Top Off

Current Loss while Ramping

10 GeV Copper Linac
5-10 GeV Static Ring



Electron Source	**Polarization >~ 70%** **10 μs** **1 Hz** **< 1% Duty Factor**	
Linac	**2 GeV Copper** **2.856 GHz** **SLED RF compression, 20 MV/m** **500 m Active Length** **600 m Total Length** **<2 μs** **10 Hz** **<0.1% Duty Factor**	
Recirculation	**None**	
Ring	**Static Ring** **$\tau_{Polarization}$ > > Electron Storage Time**	
Polarization	**Determined by Injection, Spinflipper**	

~ 1 Minute Fill

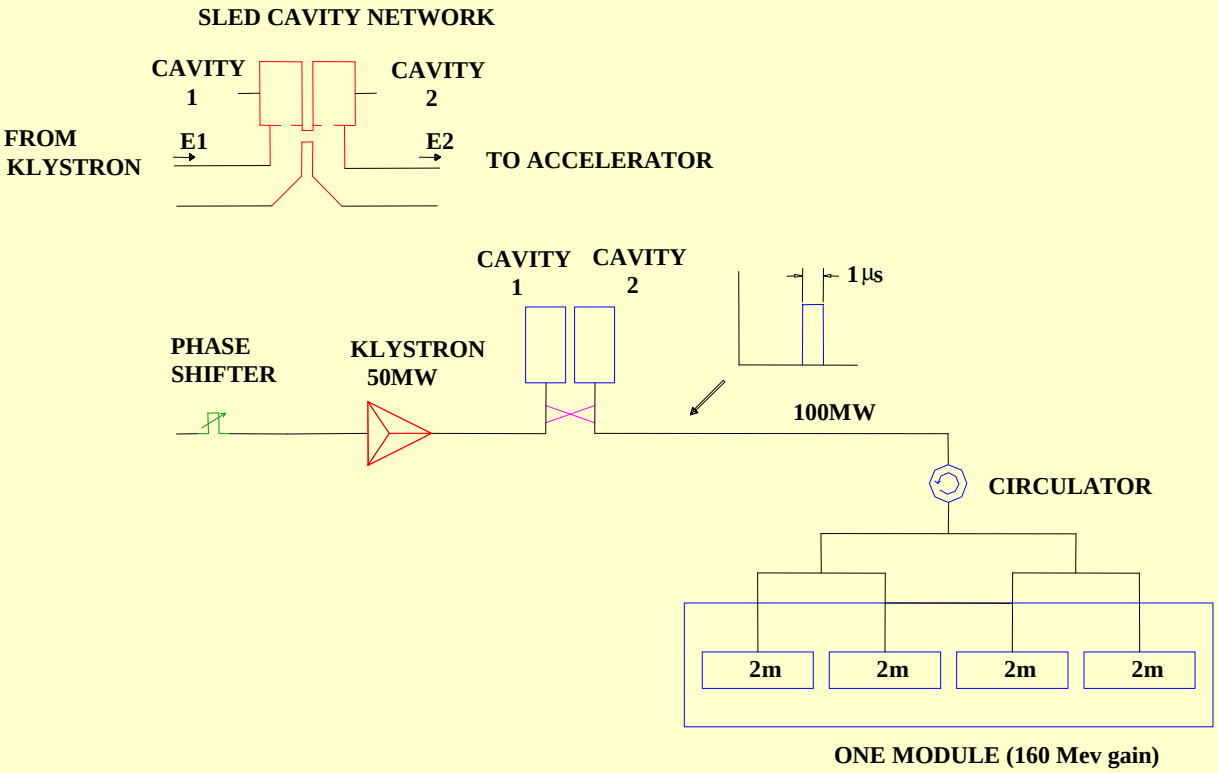
> 10 minutes Store

Live time $\eta > 90\%$

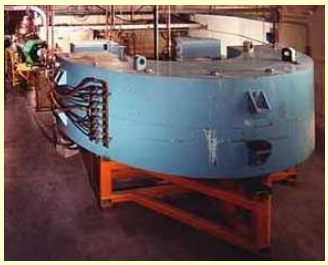
Top off allowed by Linac

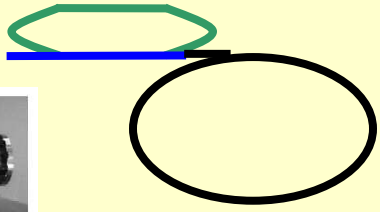
RF Compression

MICROWAVE NETWORK WITH SLED CAVITY



5 GeV Superconducting Linac
One Recirculation
5-10 GeV Static Ring





Electron Source	**Polarization = 70%** **10 μs** **1 Hz** **< 1% Duty Factor**	
Linac	**5 GeV SRF** **1.3 GHz** **12 klystrons, 10 MW, 20 MV/m** **250 m Active Length** **375 m Total Length** **1 ms** **10 Hz** **~1% Duty Factor**	
Recirculation	**One Recirculation** **Bates Bends, ~ 1.5T, 5 GeV/c**	
Ring	**Static Ring** **$\tau_{Polarization}$ > > Electron Storage Time**	
Polarization	**Determined by Injection**	

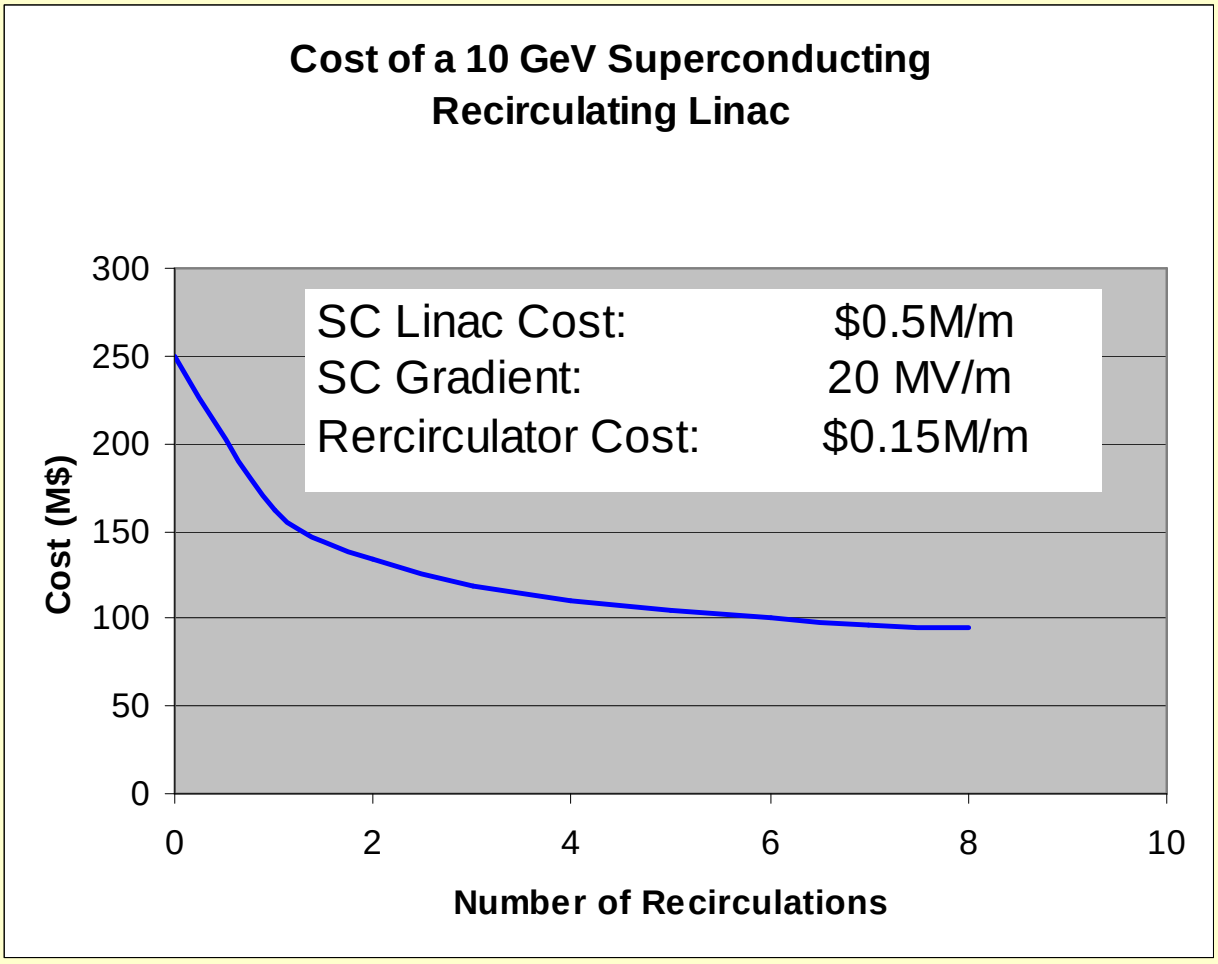
~ 1 Minute Fill

> 10 Minutes Store

Live time η ~ 90%

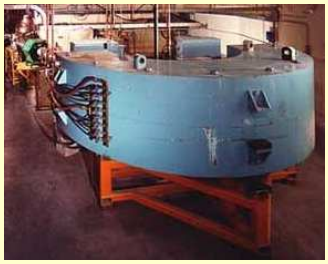
Top Off Allowed by Linac

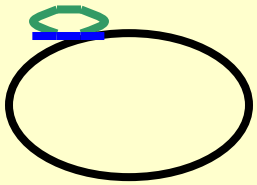
Optimization of Number of Recirculation Passes



Above is in conflict w/ JLAB experience
Compare 5 MeV/m JLAB w/ TESLA 20 MeV/m

1 GeV Copper Linac
One Recirculation
2-10 GeV Ramping Ring





Electron Source	**Unpolarized** **1 μs** **10 Hz** **<1% Duty Factor**
Linac	**1 GeV Copper** **2.856 GHz** **10 MV/m** **100 m Active Length** **125 m Total Length** **3 μs** **10 Hz** **< 1% Duty Factor**
Recirculation	**One Recirculation** **Bates Bends**
Ring	**Ramping Ring** **Radiation and Damping Wigglers** **$\tau_{Polarization}$ << Cycle Time**
Polarization	**Polarize in Ring** **Determined by Sokolov Ternov**

~ 1 Minute Fill

>~ 10 Minutes Ramp/Polarize

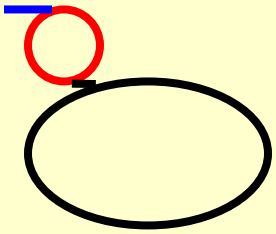
>~ 1 Hr Store

Live time $\eta \sim 80\%$

No Top Off

Current Loss while Ramping

2 GeV Copper Linac
2-10 GeV Booster Ring
5-10 GeV Static Ring



Electron Source	**Unpolarized** **1 us** **10 Hz** **< 1% Duty Factor**	
Linac	**2 GeV Copper** **2.856 GHz** **SLED RF compression, 20 MV/m** **100 m Active Length** **125 m Total Length** **< 2 μs** **10 Hz** **<1% Duty Factor**	~ 2 Minutes Fill
Booster	**~200 m Circumference**	>~ 10 Minutes Ramp/Polarize
Ring	**Static Ring** **$\tau_{Polarization}$ > > Cycle Time**	> 1 Hour Store
Polarization	**Polarize in Booster** **Determined by Sokolov Ternov**	

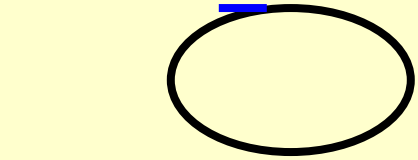
Live time $\eta \sim 75\%$

Top Off ?

Injection Options

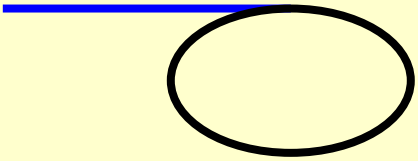
$56M

2 GeV Copper Linac
2-10 GeV Ramping Ring



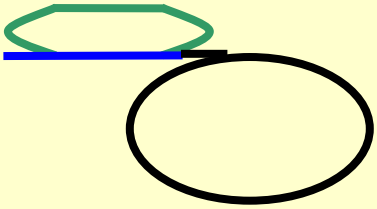
$163M

10 GeV Copper Linac
5-10 GeV Static Ring



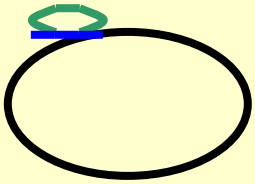
$148M

5 GeV Superconducting Linac
One Recirculation
5-10 GeV Static Ring



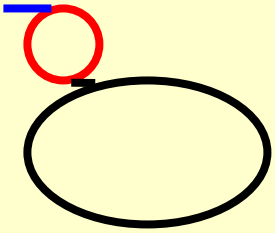
$51M

1 GeV Copper Linac
One Recirculation
2-10 GeV Ramping Ring



$131M

2 GeV Copper Linac
2-10 GeV Ramping Booster Ring
5-10 GeV Static Ring



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Summary

1) On Energy Injector Provides Many Attractive Features (Polarized Injection, Short Fill Times, Topoff, Low Radiation Load in Main Ring, Maximum Currents) but is an expensive option.
2) Booster Ring is not an attractive option. Cost is comparable to on energy injection with much greater fill times.
3) Polarized Positrons require self polarization in main ring or Booster.
4) Recirculating Linacs are preferable (less expensive) to a single pass linac
5) Recirculating Linac is not viable for High Gradient Sledded Copper Structure. (1 us RF Pulse is too short.)
6) Superconducting Linacs may be cost competitive with Copper structures for on energy injection due to higher gradients and recirculation.